

# Mobility in cities: Distributional impact analysis of transportation improvements in São Paulo Metropolitan Region

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## 1. Introduction

Good connectivity within cities is an essential input for productivity and livability in cities, but the distributive impacts of improvements in within-city mobility are not well understood. This work aims at filling this gap by exploring the impacts of alternative infrastructure investments and mobility policies on economic growth, income distribution of households and internal distribution of economic activity.

This paper focuses on the estimation of the impacts of transportation investments/policies using a spatial computable general equilibrium (SCGE) model integrated to a travel demand model, following the methodology presented in Haddad et al. (2015). In order to enhance our understanding of the distributional impacts of transportation improvements in Brazilian cities, we simulate the impact of different types of mobility investments in the São Paulo Metropolitan Region (SPMR). To explore further the income effects of infrastructure investments, we also conduct microsimulation exercises integrated to the SCGE results.

We look at ten different scenarios, which are divided into two main categories: ranging from a series of infrastructure-related interventions on the mass-transit, and policies that create disincentives to the use of private cars. In the first group, the expansion of transportation infrastructure tends to reduce the average travel time in public transportation, representing a reduction in the generalized cost<sup>1</sup> of public transportation to individuals. Therefore, travelers gain an incentive to substitute away from private modes, potentially reducing congestion. The second group of interventions relates to policies that restrict car access to the city, increasing the generalized cost of individual transportation. In such cases, potential mode switch away from cars also tends to reduce congestion. The simulations results suggest potential trade-offs between efficiency and equity in the case of policies that restrict cars' access to the city. However, infrastructure-related interventions, not surprisingly, are associated with increases in GRP (Gross

Regional Product) and, while their impacts on income distribution are relatively more modest, they suggest that improvements in the overall economy brought by transportation investments are not coming at the expense of lower-wage workers.

In what follows, we discuss the motivation for this study in section 2. We then discuss the main methodological aspects of the integrated modeling system in section 3, with emphasis on the microsimulation module that adds to the original work in Haddad et al. (2015). Results for the mobility scenarios derived from simulations using the integrated modeling framework are presented and discussed in section 4. Section 5 concludes.

## 2. Motivation and background

Cities come in different sizes and forms. However, cities that have been able to grow large and remain productive and competitive such as London, Singapore and New York, all have one thing in common: good connective infrastructure that has allowed all areas of the city to remain connected. Thus, connectivity made it possible for these cities to grow as single entities.

Connectivity is essential for the success of a city for several reasons. First, firms benefit from good links to their input and output markets. A well-connected city provides firms with a larger pool of labor and bigger markets to sell their products. Second, households also benefit from good connections in a city. They can reach more opportunities in shorter times, and have access to larger pools of goods, including housing, to choose from. When households and firms are well connected, productivity and livability can be higher (Fernald, 1999; Ghani et al., 2012; Rospabé and Selod, 2006; Gobillon et al., 2007; Gobillon and Selod, 2014; Cao and Pan, 2016).

Improvements to connectivity can be achieved in at least two ways. First, by reducing the cost of transportation per unit of distance

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<sup>1</sup> The term “generalized cost” refers to the weighted sum of the monetary and non-monetary costs of a journey.

traveled. This can be done either through infrastructure investments that reduce commuting times between different points in the city, through subsidies that reduce the fare paid by consumers, or through demand management instruments that reduce congestion and commuting times. Second, policymakers can also reduce the distance between jobs and households locations, by providing incentives for the co-location of these two types of actors through zoning and land use planning decisions. Policies and investments along these two lines should be seen as complements rather than substitutes, as coordinated land use and transportation planning could help increasing densities that allow the economies of scale needed in transportation systems to be exploited, while also managing the negative externalities that arise from concentration of firms and people, such as congestion and pollution.

Computable general equilibrium (CGE) models have been used in the literature to estimate the effects of improvements in transportation infrastructure and transportation policy changes on macroeconomic variables as well as to assess the impact that such investments may have on the overall income distribution (World Bank, 2008; Haddad and Hewings, 2005; Haddad et al., 2015; Kim et al., 2004, among others). More recently, a SCGE model integrated to a transportation model that measures accessibility in the SPMR has been applied to estimate the economic impacts of the subway system, and to assess the impacts of alternative investments on the local and national economy (Haddad et al., 2015).

In this paper, we take a step forward in trying to understand the impacts of improvements to intra-city connectivity on household income distribution, by combining the SCGE model with a microsimulation model that evaluates the impact of investments and other policy changes on households' incomes. We also extend previous work by considering improvements to the city transportation network that go beyond the existing metro infrastructure and include scenarios that consider both improvements to the transportation network and demand management alternatives.

As mentioned above, policymakers have two main sets of instruments at hand to improve connectivity in a city: on one hand, investments in the physical infrastructure and demand management strategies that reduce the cost of transportation per distance traveled, and on the other hand, land use policies that reduce the distance traveled. To keep results tractable, in this work we focus on the first of these two sets, specifically investigating the impacts of infrastructure investments that reduce the generalized cost of public transportation and the use of regulations deterring the use of private vehicles in the central areas of the SPMR. Hence, we leave aside the second set of instruments related to land use management policies. However, we recognize this as a limitation of the current exercise and we highlight this as an important extension that can be considered in future work.

### 2.1. Transportation challenges in São Paulo metropolitan region

As cities grow in size and income, connectivity challenges become more complex. For example, demand for private cars increases with income, and hence pollution and congestion tend to rise. Similarly, as demand for land increases with more people and firms coming to the city, the poor are often forced to locate in peripheral areas where land is cheaper but opportunities are limited. São Paulo is no exception. A large proportion of the poorest households are located in peripheral areas, where density of employment is low and connective infrastructure is weak (Vilaça, 2011). Forced to live in areas where land is affordable but opportunities are limited, these households are left behind bearing high costs (monetary as well as non-monetary, e.g. time) and remaining in poverty.

The SPMR is home for more than 20 million people, or approximately 10% of the Brazilian population, making it the largest urban area in the country. Similar to other developing world cities, the urban structure of São Paulo is characterized by a traditional monocentric

pattern where the broad central business district (CBD) concentrates a great share of the jobs while households are spread across the territory. Combined, these two factors lead to a daily commuting flow of over one million workers going from peripheral residential regions to the metropolitan business centers in the central and western zones of the city. Moreover, connectivity is weaker in regions which are farther from the wealthier central part of the urban area, and the diffuse pattern of job decentralization hinders the access of workers with no car to potential employers that are located far from the focal points of transit accessibility (Haddad and Barufi, 2017).

To tackle connectivity challenges, the City of São Paulo together with the State government have taken important steps to improve connective infrastructure in the metropolitan area, investing in the construction and expansion of the underground metro system, improving the existing suburban rail network, and physically integrating the various modes of public transportation. However, challenges remain. Today, about 31 percent of trips are done in private vehicles, 37 percent with public transportation, and 32 percent with non-motorized vehicles (METRO, 2008). The metro system is 78.5 km in length, and, while it is one of the most productive in the world in terms of passengers per kilometer and passengers per car-kilometer, its mode share is still low when compared to other metropolitan areas of similar size, mainly because of its limited extension. The metro is complemented by 261 km of suburban railways and a municipal bus system with around 4500 km of routes and 15,000 vehicles. The city also has a roadway network of about 17,000 km, and the municipality has recently invested on a significant expansion of the bikeways and bus corridors, adding 400 km of bikeways and 400 km of bus-only lanes on existing roadways (World Bank, 2008).

There are currently different investments under consideration and planned for the next 10–15 years. However, the impacts of infrastructure investments on employment and on household income distribution are yet to be understood. By defining different scenarios of infrastructure investments and mobility policies, this work assesses the impacts of transportation-related interventions in the SPMR on growth, household income distribution, the location of economic activities within the metropolitan area, as well as CO<sub>2</sub> emissions.

### 3. Overview of the methodology

The methodology followed in this work has two main stages, calibration and microsimulation. In the first stage, a travel demand model, a wage equation and a SCGE are defined using the baseline data for the SPMR. In the second stage, the policy and investment scenarios are defined. For each scenario, the transportation model is used to calculate the changes on travel time and mode demand. These results are used as inputs to calculate productivity shocks through the wage equation estimated in the previous stage. The results of this simulation feed the SCGE model, which computes the effects of productivity shocks on sectoral output, income and employment in different parts of the metropolitan region. Through microsimulation techniques, the results of the SCGE are then used to assess the equilibrium impacts on income inequality. Fig. 1 describes the path followed in the modeling framework and the integration of all its parts, discussed in detail in Haddad et al. (2015), and Vieira and Haddad (2015). In what follows, we discuss in further details the add-ons in the second stage of our methodology, that is, the microsimulation steps introduced in this paper.

#### 3.1. Estimating the distributional impacts of transportation policy changes – the microsimulation module

Microsimulation is a technique commonly used to model the behavior of individuals by evaluating the observed attributes of a representative population that are jointly distributed (Clarke and Holm, 1987). In our framework, microsimulation is used to estimate how productivity and labor income of workers would be affected by changes

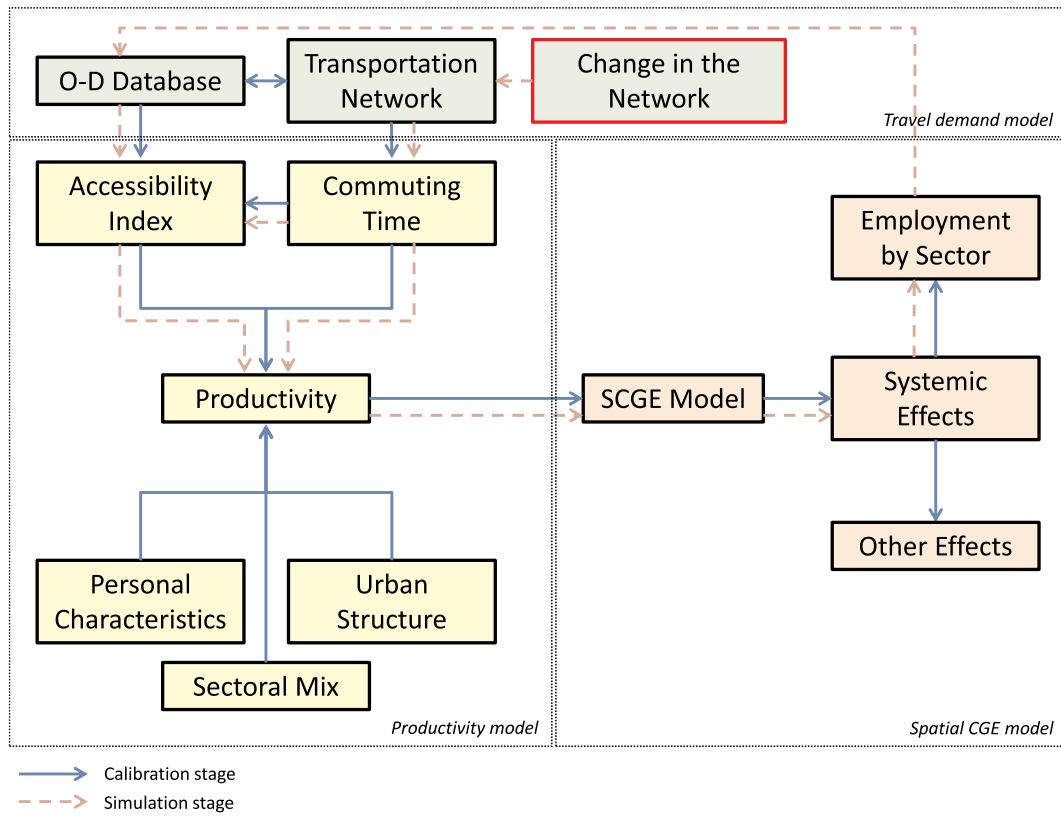


Fig. 1. The integrated modeling framework.

Source: Haddad et al. (2015).

in transportation policies and infrastructure investments, using information from the most recent Origin Destination (OD) Survey. The OD Survey divided the SPMR into 460 traffic zones (TAZs).<sup>2</sup> While the OD Survey in São Paulo is not designed to collect detailed income or consumption information, the income variable does appear to provide a good approximation to the income distribution in the SPMR when compared to PNAD data.<sup>3</sup>

Our microsimulation, as it interacts with the SCGE model results, can be divided into two steps. First, with the definition of the investments and policy changes in each scenario, we use the transportation model to forecast changes on travel time and mode demand. Based on the estimated parameters of the wage equation (productivity model), these results lead to direct impacts on workers' productivity. In the second step, this variation in productivity is an input for the SCGE model, which interacts back with the microsimulation by shifting the distribution of employment over the urban area, altering the accessibility of individuals. Then the results on workers' income and

commuting time are further evaluated.

### 3.2. Step 1 – using the results of the transportation model

For each scenario, the transportation model<sup>4</sup> estimates among other results: (1) average changes in travel time by mode and TAZ pair ( $\tau_{m,od}$ ); (2) total mode demand by TAZ pair, ( $Y'_{m,od}$ ).

We define the baseline travel time by mode  $m$  between TAZ pair  $od$  as  $t_{od,m}^0$ , and the corresponding new simulated travel times for each scenario are described by  $t'_{od,m}$ . Therefore, in order to connect the results from the transportation model to our individual level microsimulation, we associate the transportation model average changes in travel time by mode and TAZ pair ( $\tau_{m,od}$ ) to workers based on their place of residence ( $o$ ) and employment ( $d$ ). That is, the new travel time  $t'_{i,m,od}$  for each worker is calculated as:

$$t'_{i,m,od} = t_{i,m,od}^0 + \tau_{m,od} \quad (1)$$

Where  $t_{i,m,od}^0$  is the original commuting time of workers observed in the OD Survey, and  $m$  the mode of transportation used by this worker.

Moreover, from the transportation model estimates of mode demand  $Y'_{od,m}$  per TAZ pair, we calculate for each scenario the new total mode demand  $Y'_m$  for the whole SPMR.

$$Y'_m = \sum_{od} Y'_{od,m} \quad (2)$$

The changes in total mode demand are distributed throughout workers through an adjustment on their sample weights  $\phi_i$ .<sup>5</sup>

<sup>2</sup> The sample of the OD Survey is based on a stratification of households according to their consumption of electricity as a proxy for income levels. Households were divided into 4 consumption levels: 0–100, 100–200, 200–300, 300–more kwh/month. Therefore, the sample for each TAZ was randomly selected conditional on the share of households in the population within each consumption bin. Data was collected for all individuals living in selected households. Information about trips was related to the day immediately before the interview. For example, Saturday interviews collected information about trips made on Friday. The Metropolitan Region was divided into 460 TAZs, and the number of households in the sample was defined such that the margin of error for the number of trips originated in each TAZ would be inferior to 5% at 95% confidence. The final sample included 30,000 households.

<sup>3</sup> PNAD is a national household survey conducted yearly by the Brazilian Institute of Geography and Statistics (IBGE) that is focused on demographic and socioeconomic information of the population.

<sup>4</sup> The transportation model is discussed in further details in Appendix A1.

<sup>5</sup> Sample weights were calculated in the original OD Survey (METRO, 2008).

$$\phi'_i = \phi_i^0 \left( \frac{Y'_{od,m}}{Y^0_{od,m}} \right) \quad (\forall \quad i \mid m_i = m) \quad (3)$$

And a RAS<sup>6</sup> iterative proportional fitting algorithm is used to keep constant the share of residents and workers in each TAZ pair.<sup>7</sup>

$$Y'_{od} = Y^0_{od} \quad (4)$$

Moreover, the new travel times from the transportation model lead to a new value for the accessibility  $a_i$  of workers.

$$a'_i = \sum_d \frac{E_d^0}{\delta(t'_{od})} \quad (5)$$

Where  $E_d^0$  is the baseline number of jobs in each TAZ and  $\delta(\cdot)$  is a deterrence function capturing the effect of travel time on accessibility.

Following Haddad et al. (2015), we assume that both travel time and accessibility changes affect the productivity of workers. The average effect of these variables on productivity are represented by the coefficients  $\beta_a$  and  $\beta_t$  estimated by a linear wage equation. We use the parameters estimated by Haddad et al. (2015) and the travel time and accessibility changes calculated by our transportation model to estimate changes in the productivity  $w'_i$  of workers from the OD sample

$$w'_i = \hat{\beta}_a \frac{a'_{od}}{a^0_{od}} + \hat{\beta}_t \frac{t'_{od}}{t^0_{od}} \quad (6)$$

Finally, we aggregate the average productivity change  $W'$  for each municipality  $mun$ , both in terms of workers' place of residence and employment. This matrix of productivity changes is used as input for a SCGE model shock.

$$W'_{mun} = W^0_{mun} \left( \frac{\sum_i w'_i \phi'_i}{\sum_i w^0_i \phi^0_i} \right) \quad (7)$$

### 3.3. Step 2 – using the results of the SCGE model

From the productivity shocks described above, the SCGE model<sup>8</sup> produces a vector of employment and population changes for each municipality. This vector is used to recalculate the sample weight  $\phi_i$  of workers according to their city of employment and residence.<sup>9</sup> The redistribution of employment leads to a new vector of accessibility, which is used to calculate a new productivity shock, which is again aggregated and used as input in the SCGE model. This process is repeated until convergence is reached, and then the wages of workers are adjusted so that the overall real income by municipality is equivalent to the values calculated by the last iteration of the SCGE model.

### 3.4. CO<sub>2</sub> emissions module

Furthermore, we have implemented a module for computing vehicle

<sup>6</sup> Also known as a “biproportional” matrix balancing technique (Miller and Blair, 2009).

<sup>7</sup> The adjustment of sample weights allows us to incorporate into our microsimulation the mode demand changes calculated by the transportation model, without changing employment and population in a TAZ. Moreover, by keeping constant the number of residents and employment in the each TAZ pair, we guarantee we do not affect the employment and population levels before running the SCGE model. Such changes are later accounted for in the SCGE component of our model, in step 2.

<sup>8</sup> The analytical, functional and numerical structures of the SCGE model are presented in Appendix A2.

<sup>9</sup> The SCGE model generates outputs at the municipality level. Thus, changes in population and employment in each municipality are applied proportionally to each TAZ pertaining to a municipality. This downscaling procedure guarantees that we are able to introduce the simulated changes in the number of residents and jobs only at the city level without changing the composition by TAZ in each city.

emissions in each simulated scenario. Despite its relatively simplistic approach, such calculations generate partial estimates that provide initial insights on the effects on CO<sub>2</sub> emissions associated with different mobility policies.

Data from the State Environmental Agency (CETESB) were used to compute CO<sub>2</sub> emission factors (g/l) by type of fuel used in vehicles. The amount of gas emitted depends directly on the amount of fuel consumed (in liters) by the vehicle on its journey. The following factors were adopted in this study: (i) Automobiles – 1.91 g/l (average consumption of ethanol (41%) and gasoline (59%) in BOE (barrel of oil equivalent) in 2015; (ii) trucks – 2.6 g/l.<sup>10</sup>

We have considered that CO<sub>2</sub> emissions depend directly on the amount of fuel consumed by vehicles. Fuel consumption, on its hand, depends on distance traveled and on average speed (km/h).

Performance curves (fuel consumption (l) x average speed (km/h)) were estimated using the software *HDM-VOC*. In this analysis, four types of vehicles were considered: (i) small cars; (ii) large cars; (iii) light trucks (2 and 3 axles); and (iv) heavy trucks (4 or more axles).

The average distances and speeds reached in each trip were obtained from the traffic simulation model. From these data, the average fuel consumption in each scenario was calculated and, subsequently, the resulting CO<sub>2</sub> emissions were estimated.

## 4. Results

We evaluate the impact of the following ten scenarios, as described in Table 1. The first four policy scenarios refer to infrastructure investments in the expansion of metro, train, and bus corridors. The definition of these scenarios was based on current investment plans to 2020 and 2025. Scenarios 6 to 10 focus instead on demand management policies that impose out-of-the-pocket payments mainly to private vehicle users. Scenario 5 provides a combination of the two, including investments in infrastructure and an increase in fuel prices.<sup>11</sup>

Table 2 presents the results for the main impacts generated by the simulations, considering long run impacts of each scenario. In what follows, we present estimates for different indicators for the SPMR, highlighting some of the results that shed light on the potential trade-offs of the distributional impacts.

Fig. 2 reveals the direct relationship between average commuting time and real GRP growth. Commuting time affects productivity through two main channels, as described in Haddad et al. (2015). Long commute is expected to decrease workers' productivity as longer commuting time may induce workers to arrive late at work, or leave earlier, and increase the number of absent days (Van Ommeren and Gutiérrez-I-Puigarnau, 2009); moreover workers experiencing longer commuting trips may also become less productive as they provide lower effort levels than those residing closer to jobs (Zenou, 2002). Agglomeration economies are also expected to positively influence workers' earnings. Workers are paid more in larger and denser markets because they are more productive there due to the presence of agglomeration economies (Melo and Graham, 2009). In this case, better mobility improves accessibility to job, which approaches workers and firms favoring a more efficient matching in the urban labor market. Since productivity is inextricably linked to long-term growth, the relationship depicted in Fig. 2 follows.

Fig. 3 summarizes some of the main results of Table 2, considering selected indicators. The graph contains information on three different dimensions. The x-axis presents the growth impacts on the SPMR GRP,

<sup>10</sup> It was considered that trucks runs only on diesel, and automobiles runs on both gasoline and ethanol. For the latter, an average emission factor was estimated based on the total gasoline and ethanol consumption throughout the year of 2015, according to the National Agency of Petroleum, Natural Gas and Biofuels (ANP).

<sup>11</sup> See Appendix 3 to additional information on the policy scenarios.

**Table 1**  
Investment and policy scenarios.

Scenarios		Simulations	
		Variables	TAZs
<i>Investments Only</i>			
1	Metro and Train developments until year 2020	Travel time by public mode	All pairs with investments
2	Metro, Train and Bus corridor development until year 2020	Travel time by public mode	All pairs with investments
3	Metro and Train developments until year 2025	Travel time by public mode	All pairs with investments
4	Metro, Train and Bus corridor development until year 2025	Travel time by public mode	All pairs with investments
<i>Investments + Tax</i>			
5	Metro, Train and Bus corridor development until year 2025, and 30% increase in fuel price	Travel Time by public mode; Generalized cost of private mode	All pairs with investments; All TAZ pairs
<i>Changes in policies (fees, toll, tax)</i>			
6	30% increase of in fuel prices	Generalized cost of private mode	All TAZ pairs
7	Implementation of urban toll (R\$5,00)	Generalized cost of private mode	Extended CBD TAZs pairs
8	50% increase in parking cost in the entire SPMR	Generalized cost of private mode	All TAZ pairs
9	50% increase in parking cost in the extended CBD	Generalized cost of private mode	Extended CBD TAZs pairs
10	50% increase in parking cost in the core of the CBD	Generalized cost of private mode	Extended CBD TAZs pairs

**Table 2**  
Summary of long-run impacts.

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
<b>Travel Demand</b>											
Transit trips (% in total)	56.99	56.97	57.03	57.27	57.38	61.04	60.28	60.42	58.00	57.67	58.86
Generalized cost of private vehicle trips (in % change)	-	-0.095	-0.202	-0.457	-0.739	16.827	18.136	17.820	-0.599	-0.754	-0.555
Generalized cost of transit trips (in % change)	-	-4.721	-4.985	-6.716	-7.077	-7.601	-0.892	-0.344	-0.311	-0.262	-0.526
<b>Gini</b>											
Wage	0.6006	0.5976	0.5970	0.5957	0.5948	0.5847	0.5907	0.5893	0.5982	0.5990	0.5959
Commuting time	0.4120	0.4020	0.4010	0.3990	0.3973	0.3904	0.4044	0.3979	0.4094	0.4104	0.4061
<b>p 90/p 10</b>											
Wage	4.65	4.66	4.65	4.74	4.54	4.25	4.63	4.67	4.65	4.65	4.66
Commuting time	11.00	8.07	8.07	10.93	8.56	9.12	11.00	13.05	10.47	10.81	11.04
<b>Average Indicators</b>											
Wage (BRL)	761.91	783.03	784.41	793.29	796.24	781.85	748.90	746.38	760.91	761.70	759.27
Commuting time (min)	52.14	50.25	50.07	49.55	49.23	50.57	53.41	54.50	52.33	52.20	52.70
SPMR GRP (in % change)	-	0.879	0.919	1.259	1.362	0.205	-1.049	-1.278	-0.166	-0.092	-0.354
<b>Locational Gini</b>											
Equal weights	0.8461	0.8460	0.8460	0.8461	0.8460	0.8457	0.8457	0.8455	0.8460	0.8460	0.8459
Population weight	0.1602	0.1604	0.1604	0.1605	0.1602	0.1581	0.1583	0.1563	0.1595	0.1597	0.1589
<b>CO2 Emissions (kg per type of vehicle)</b>											
Automobiles (in % change)	-	-5.685	-5.801	-6.714	-7.094	-16.811	-13.737	-9.589	-2.090	-1.595	-3.505
Trucks (in % change)	-	-0.042	0.084	0.139	0.042	-0.042	-0.014	-0.097	-0.014	0.125	-0.028
<b>Qualitative indicators</b>											
Political cost	-	Low	Low	Low	Low	High	High	High	High	High	High
Financing cost	-	High	High	High	High	High	Low	Low	Low	Low	Low

and the y-axis presents the percentage change in the Gini for labor income. The third piece of information relates to the locational Gini calculated using population weights: warmer colors (*reddish*) represent increases in concentration of economic activity, while cold colors (*green*) are associated with dispersion of the activity level within the SPMR – in both cases, darker colors refer to stronger effects.

Overall, the impacts of the two main groups of interventions point in two different directions. First, scenarios 1 to 4, which are associated with infrastructure investments on public transportation, are all pro-growth and reduce overall commuting time. It is also clear that, as the portfolios of investments considered include a larger array of interventions (both in terms of different types of infrastructure and over time), the effects are magnified, with larger impacts for scenarios 3 and 4 which consider expansions planned until 2025. We find that investments in transportation contribute to equalizing wages across space as barriers to mobility decline, favoring concentration of economic activity.

Second, scenarios 6–10, which are associated with mobility policies

that impose out-of-the pocket payments mainly to private vehicle users, point to effects that reduce economic growth of the SPMR. They contribute to reducing inequalities in accessibility and labor income and to promoting decentralization of the economic activity within the SPMR. They do so with increases in overall average commuting times and lower levels of overall welfare, as measured by the average real wage. Scenario 5, which represents a mix between the two groups of interventions, shows stronger effects on public transit demand, income and spatial inequality but lower impacts on GRP growth and smaller reductions in overall commuting times.

One dimension that is not included in the model but that is also important to consider is the political economy of the policy changes included in the scenarios. While for the group of infrastructure interventions the financial cost may be high, the political cost is relatively low. Instead, for policies that impose extra costs to car users, such as the urban toll, the political costs may be very high, despite the relatively low financial cost related to the implementation of such set of policies.

Finally, the results also show that the most significant changes

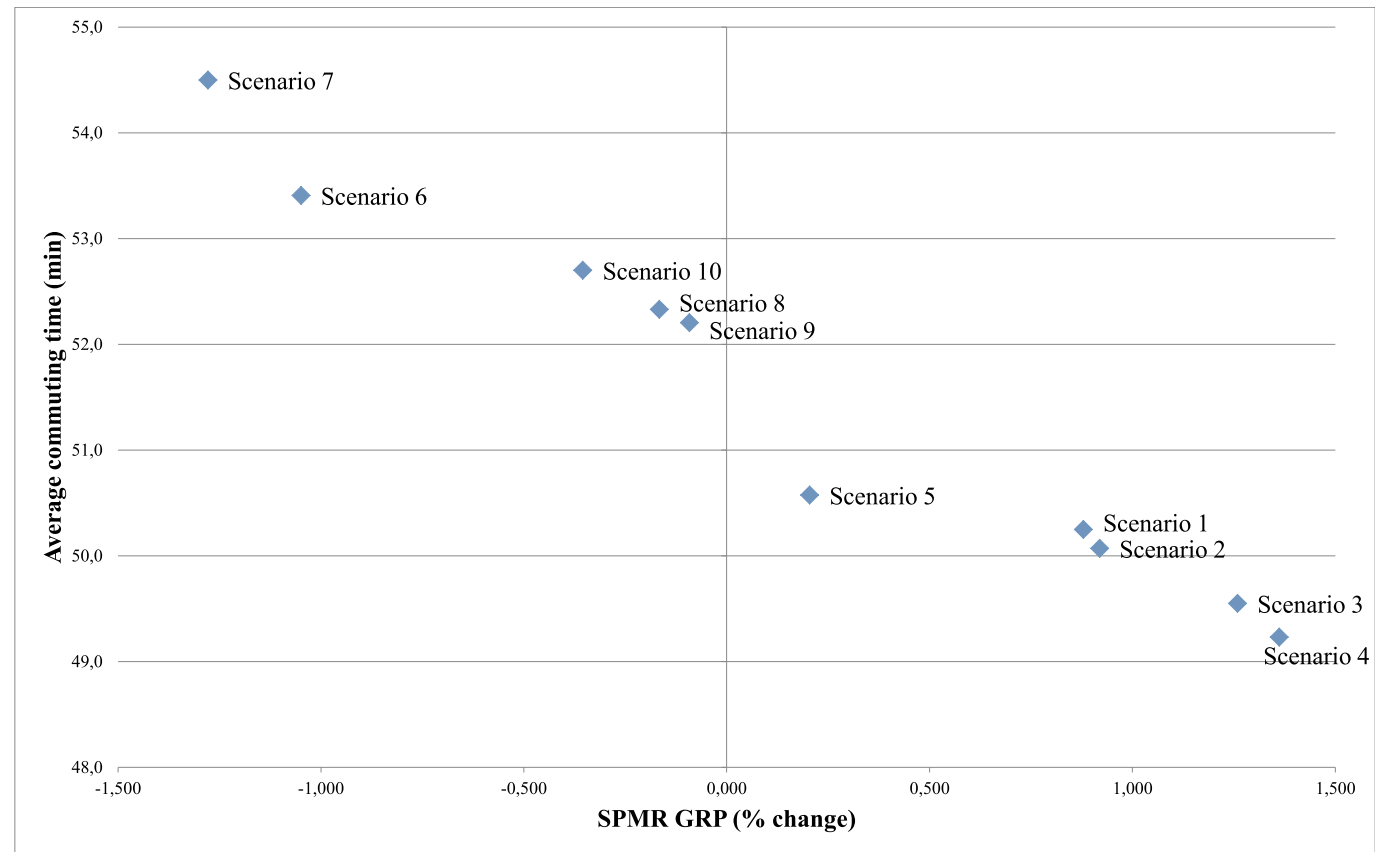


Fig. 2. Commuting time and GRP growth.



Fig. 3. Summary of aggregate results.



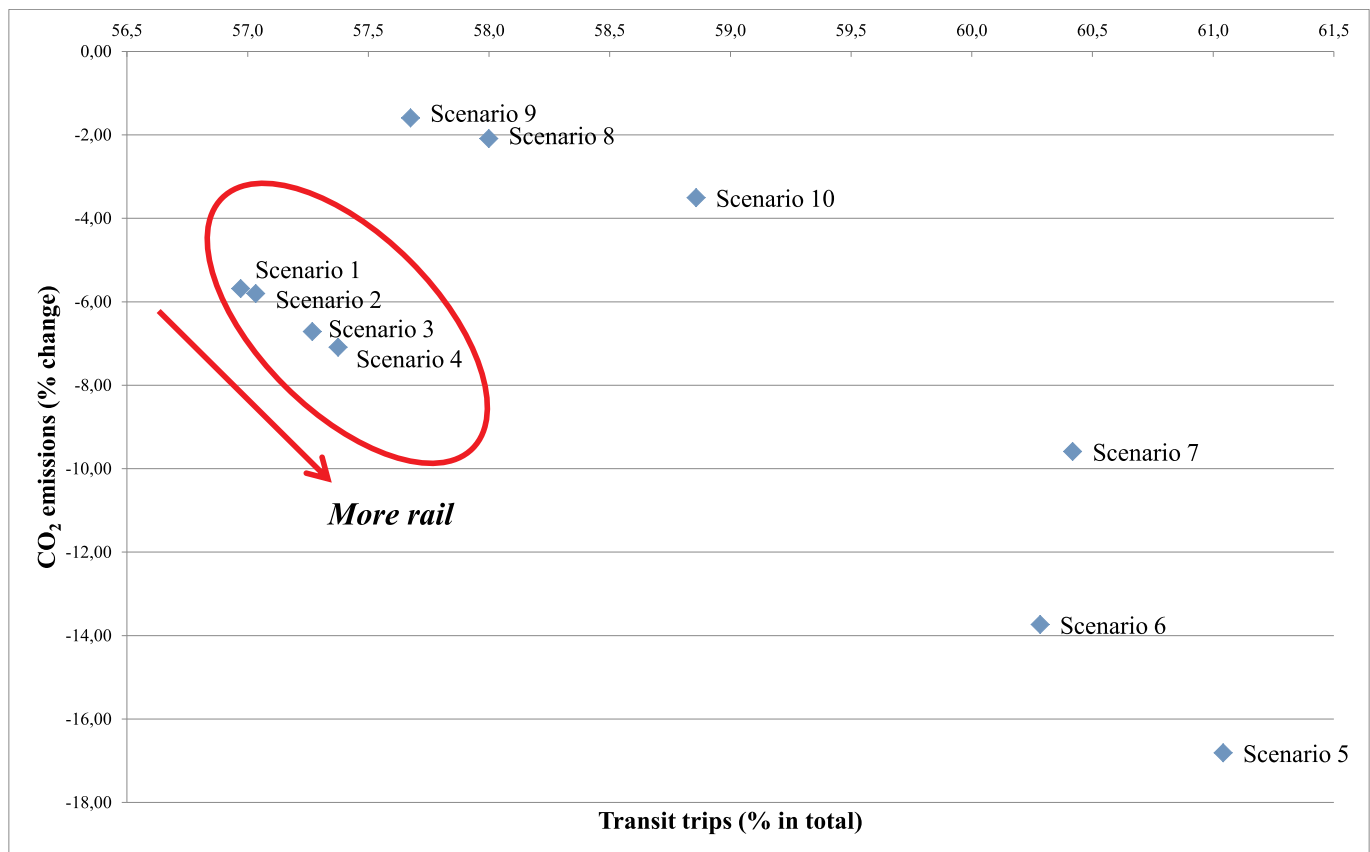


Fig. 4. Mode shifts and CO<sub>2</sub> emissions.

toward mass transit modes are seen in scenarios 5, 6, and 7 as they impose restrictions to auto use. The fact that scenarios 1 through 4 are not reflecting the largest changes in public transit demand confirms the well-known fact that supply side efforts are not enough to encourage users to substitute from private vehicle trips to mass transportation modes. These results have direct implications to the results related to CO<sub>2</sub> emissions, which also show scenarios 5, 6 and 7 as those with higher potential to reduce transit-related pollution in the SPMR (Fig. 4). In the case of the expansion of the physical infrastructure, the results reveal that mode shifts towards more rail public transit use (scenarios 3 and 4) bring potentially more benefits for the environment.

## 5. Conclusion

This work simulated a set of alternative mobility policies and investments for the São Paulo Metropolitan Region. The analysis was based on a framework that integrates a transportation model, capturing the structural effects of each policy, with a SCGE model that allows the assessment of the economic impacts of such changes. Further exploration of the income effects of the policies was done to assess their distributional impacts.

The results from this work suggest, not surprisingly, that investments in transportation infrastructure are associated with increases in GRP. Further, while the impacts of such investments on income distribution are relatively modest, they do suggest that improvements in the overall economic efficiency brought by transportation investments are not coming at the expense of the lower income workers. Results indicate that investments in the infrastructure of mass transportation systems can lead to substantial economic gains for the metropolitan area. For all infrastructure investment scenarios, average increases in GRP throughout the region fall above 0.8%. Impacts in commuting times and income vary across the region but on average, larger decreases in commuting times are achieved through the infrastructure

scenarios. On the other hand, in the case of policies that increase the individual cost of private vehicle users, the overall impact on economic growth is negative, while their distributional impacts are relatively stronger in favor of income equity and spatial cohesion.

As previously stressed, this work does not take into account the land use patterns of the city, which could contribute to strengthening or weakening the observed impacts. While coordinated land use planning and transportation planning can make the layout of the city more conducive to shorter commutes than transportation investments alone, constraints in the housing market can act as barriers to the internal mobility of households and firms. Recent work for Chicago provides evidence that zoning had a broader and more significant impact on the spatial distribution of economic activity than geography or transportation networks (Shertzer et al., 2016). The jury is still out on the net effect that these may have in an urban area like the SPMR.

By accounting for the impact that the infrastructure and policy changes may have on emissions, and hence pollution and health, we add another dimension of the impacts. A move to mass transportation is usually associated with a reduction in emissions. However, this is only true when mass transportation is cleaner than cars. In cities where the bus fleet is outdated and remains unchanged, a move toward mass transport modes may in fact increase pollution and health issues may worsen. Extending the current work along these two lines can help better inform the tradeoffs that policymakers face in supporting economic growth by enhancing efficiency of the city while maintaining and improving livability.

In summary, the policy conclusions that can be derived from the results of this study indicate potential trade-offs of the different policy scenarios. This paper makes it clear that the choice of the “best” policies depends on the policy goals to be achieved. The analysis was based on the application of the integrated framework for the *ex ante* impact assessment of investment and mobility policies in a systemic context, in their operational phase. The impacts of the implementation phase were

not considered in the exercises, despite some qualitative conjectures about differences in the financial costs of each alternative. The goal was, thus, to explore the characteristics of the integrated modeling system in the operational phase and not to proceed with a systematic evaluation of each policy option, which goes beyond the possibilities of the methodology used.

### Acknowledgements

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### Appendix 1. Transport modeling framework

To assess the impacts of changes in infrastructure and operations of the transport system within the SPMR, we used a travel demand model for personal travel developed and implemented by the engineering company *TTC – Engenharia de Tráfego e de Transportes*, São Paulo, Brazil. The model consists of an aggregated trip-based classical four-step model that takes into account socioeconomic data, survey data, transportation infrastructure characteristics, and operational information to produce trip flows and times. The four steps included in the model are: (i) *Trip Generation*, which determines the number of trips (by origin and destination from/to each pre-defined zone) within a period of time, by trip purpose; (ii) *Trip Distribution*, which determines the origin-destination (OD) pairs, based on the total origin and destination trips of each zone; (iii) *Mode Choice*, which defines the proportion of trips for each OD pair that uses automobiles or public/mass transport modes; and (iv) *Assignment*, which selects which paths will be used by each OD pair and transport mode.

The variable used to quantify travel time and travel cost is referred to as the generalized cost, which is a linear combination of the weighted components of travel time (walking, waiting, in vehicle, etc.), distance, and monetary costs (fuel costs, public transportation fare, parking costs, etc.) spent on each trip.

The zone system adopted in this study is the same used in the household survey carried out by the São Paulo Metropolitan Company (Metro) in 2007, in which the SPMR was divided into 1895 micro traffic zones, from the original 460 TAZs. Fig. A1.1 illustrates the zone system used for the SPMR (in red), and the city borders of São Paulo (in black).

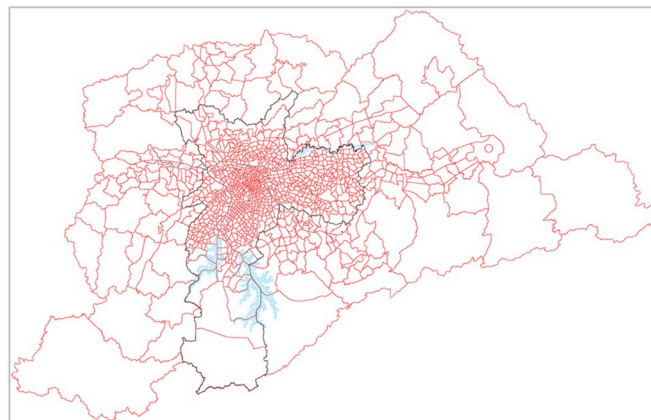


Fig. A1.1. Zone System.

Source: TTC.

The first step of the model estimates the total number of trips going out and to every single zone within the study area. This is referred to as the trip generation module. In this stage, regression models are used to relate socioeconomic and geographic variables to travel vectors obtained from the OD 2007 and its 2012 update (OD, 2012). Two sets of equations are estimated: (i) travel generation equations, which feature the following independent variables: income, self-ownership, population and family structure; and, (ii) travel attraction equations, which use employment and economic sectors as independent variables. These equations are then used to estimate trip generation and attraction for each zone.

In the second step, the vectors of trip generation and attraction obtained in the first step are used in a gravity-type model to estimate the number of trips between origin and destination pairs, creating an O-D matrix using a travel distribution model. Trips for each O-D pair are hence estimated as proportional to the number of trips leaving the origin zone and the number of trips arriving at the destination zone, and inversely proportional to the generalized travel cost between two zones.

The generalized cost between pairs of zones was calculated using a network model for both automobile and mass transit modes. For automobiles, the operational cost of the vehicle, the occupation (people-automobile ratio), travel time, and distance were considered in the calculation. For mass transit, the generalized cost considered the average walking distance, waiting time, travel time, and cost of the fare.

Calibration of the distribution model is made by comparing the travel frequency histogram obtained from the observed OD 2007/2012 surveys with the histogram obtained from the estimated matrix. The distribution model is then adjusted in an iterative manner.

In the third step, travel flows need to be broken down by mode (mass transit and automobile). A mode choice model is estimated employing a binomial logit function which considers as explanatory variables for the probability of using different transportation modes the following variables: reason for travel, income, cost and time of travel, car ownership, travel time, frequency, among others.

Finally, the software *Emme 4* is used for the assignment of paths by OD pair and mode of transport.<sup>12</sup> As previously mentioned, the simulation

<sup>12</sup> This Canadian software has been widely used for analytical work in Brazil, and has been the choice of most transit agencies in São Paulo for planning purposes.



model used for this study covers the main roads of the SPMR, in addition to all subway and rail networks. Each link has information attached on length, number of lanes, hierarchical classification, capacity, maximum speed, etc. The simulation model includes the municipal bus lines of São Paulo (regulated by SPTrans) and other 38 cities of the SPMR, intercity bus lines in the SPMR (regulated by EMTU), metropolitan passenger trains operated by the São Paulo Metropolitan Trains Company (CPTM), and the Metro lines. For each of the transit lines there is information on its physical and operational characteristics, such as itinerary, frequency, fare, vehicle type, capacity, etc. A total of 3044 unidirectional transit lines, among municipal, intercity, trains and subway are included in the model.

The simulation model adopts specific travel time functions, or volume delay functions (VDF), for calculating the distribution of automobile demand. The route assignment algorithm for automobiles assumes every car seeks to improve its travel time in each iteration until alternatives routes do not produce improvements in travel time. For mass transport, the transit time of a line at each link is computed considering the automobile time at that link. For links where there are no automobiles, the transit time is computed using a constant speed instead.

## Appendix 2. Specification of the SCGE Model

In this Appendix, we present the analytical, functional and numerical structures of the spatial computable general equilibrium model for the SPMR. The specification of the linearized form of the model is provided, based on different groups of equations. The notational convention uses uppercase letters to represent the levels of the variables and lowercase for their percentage-change representation. Superscripts ( $u$ ),  $u = 0, 1j, 2j, 3, 4, 5$ , refer, respectively, to output ( $0$ ) and to the five different regional-specific users of the products identified in the model<sup>13</sup>: producers in sector  $j$  ( $1j$ ), investors in sector  $j$  ( $2j$ ), households ( $3$ ), purchasers of exports ( $4$ ), and government ( $5$ ); the second superscript ( $r$ ) identifies the domestic region where the user is located. Inputs are identified by two subscripts: the first ( $i$ ) takes the values  $1, \dots, g$ , for commodities,  $g + 1$ , for primary factors; the second subscript identifies the source of the input, being it from domestic region  $b$  ( $1b$ ) or imported ( $2$ ), or coming from labor from domestic region  $b$  ( $1b$ ) or capital ( $2$ ), the two groups of primary factors in the model. The symbol  $(\bullet)$  is employed to indicate a sum over an index.

We define the following sets:  $G = \{1, \dots, g\}$ , where  $g$  is the number of composite goods;  $G^* = \{1, \dots, g, g + 1\}$ , where  $g + 1$  is the number of composite goods and primary factors, with  $G^* \supset G$ ;  $H = \{1, \dots, h\}$ , where  $h$  is the number of industries;  $U = \{(3), (4b), (5), (kj)\}$  for  $k = (1), (2)$  and  $j \in H$ , is the set of all users in the model;  $U^* = \{(3), (5), (kj)\}$  for  $k = (1), (2)$  and  $j \in H$ , with  $U \supset U^*$ , is the subset of domestic users;  $S = \{1, \dots, r, r + 1\}$ , where  $r + 1$  is the number of all regions (including foreign);  $S^* = \{1, \dots, r\}$ , with  $S \supset S^*$ , is the subset with the  $r$  domestic regions; and  $F = \{1, \dots, f\}$  is the set of primary factors. In the SCGE model for the SPMR,  $g = h = 8$ ,  $r = 41$ , and  $f = 2$ .

We model the sourcing of composite goods based on multilevel structures, which enable a great number of substitution possibilities. We employ nested sourcing functions for the creation of composite goods, available for consumption in the regions of the model. We assume that domestic users, i.e. firms, investors, households, and government, use combinations of composite goods specified within two-level CES nests. At the bottom level, bundles of domestically produced goods are formed as combinations of goods from different regional sources. At the top level, substitution is possible between domestically produced and imported goods. Equations (1) and (2) describe, respectively, the regional sourcing of domestic goods, and the substitution between domestic and imported products.

$$x_{(i(1b))}^{(u)r} = x_{(i(1\bullet))}^{(u)r} - \sigma 1_{(i)}^{(u)r} (p_{(i(1b))}^{(u)r} - \sum_{l \in S^*} (\frac{V(i, 1l, (u), r)}{V(i, 1\bullet, (u), r)})(p_{(i(1l))}^{(u)r})) \quad (1)$$

$i \in G$ ;  $b \in S^*$ ;  $(u) \in U^*$ ;  $r \in S^*$

where  $x_{(i(1b))}^{(u)r}$  is the demand by user ( $u$ ) in region  $r$  for good  $i$  in the domestic region ( $1b$ );  $p_{(i(1b))}^{(u)r}$  is the price paid by user ( $u$ ) in region  $r$  for good  $i$  in the domestic region ( $1b$ );  $\sigma 1_{(i)}^{(u)r}$  is a parameter measuring the user-specific elasticity of substitution between alternative domestic sources of commodity  $i$ , known as the regional trade Armington elasticity; and  $V(i, 1l, (u), r)$  is an input-output flow coefficient that measures purchasers' value of good  $i$  from domestic source  $l$  used by user ( $u$ ) in region  $r$ .

$$x_{(is)}^{(u)r} = x_{(i\bullet)}^{(u)r} - \sigma 2_{(i)}^{(u)r} (p_{(is)}^{(u)r} - \sum_{l=1,2} (\frac{V(i, l, (u), r)}{V(i, \bullet, (u), r)})(p_{(il)}^{(u)r})) \quad (2)$$

$i \in G$ ;  $s = 1\bullet, 2$ ;  $(u) \in U^*$ ;  $r \in S^*$

where  $x_{(is)}^{(u)r}$  is the demand by user ( $u$ ) in region  $r$  for either the domestic composite or the foreign good  $i$ ;  $p_{(is)}^{(u)r}$  is the price paid by user ( $u$ ) in region  $r$  for either the domestic composite or the foreign good  $i$ ;  $\sigma 2_{(i)}^{(u)r}$  is a parameter measuring the user-specific elasticity of substitution between the domestic bundle and imports of good  $i$ , known as the international trade Armington elasticity; and  $V(i, l, (u), r)$  is an input-output flow coefficient that measures purchasers' value of good  $i$  from either the aggregate domestic source or the foreign source  $l$  used by user ( $u$ ) in region  $r$ .

In addition to goods used as intermediate inputs, firms in the model also demand primary factors of production. The equations that describe the industry  $j$ 's demands inputs are derived under the assumption of Leontief technology with Armington nests (imperfect substitution between inputs of the same type from different sources). In our specification of the nested production functions, we assume firms to use combinations of composite intermediate inputs, formed according to Equations (1) and (2), and primary factor composites. In the case of the primary factor bundle, substitution is possible among different types of primary factors. Equation (3) specifies the substitution between a composite labor input and capital in the model, and is derived under the assumption that industries choose their primary factor inputs to minimize costs subject to obtaining sufficient primary factor inputs to satisfy their technical requirements (nested Leontief/CES specification). We have included technical change variables to allow for factor-specific productivity shocks.

$$x_{(g+1,s)}^{(1j)r} - a_{(g+1,s)}^{(1j)r} = x_{(g+1,\bullet)}^{(1j)r} - \sigma 3_{(g+1)}^{(1j)r} (p_{(g+1,s)}^{(1j)r} + a_{(g+1,s)}^{(1j)r} - \sum_{l \in F} (\frac{V(g+1, l, (1j), r)}{V(g+1, \bullet, (1j), r)})(p_{(g+1,l)}^{(1j)r} + a_{(g+1,l)}^{(1j)r})) \quad (3)$$

$j \in H$ ;  $s \in F$ ;  $r \in S^*$

<sup>13</sup> We have specified a sixth residual user, ( $6$ ), to deal with statistical discrepancies in the balancing of the model's absorption matrix based on the SPMR interregional input-output system (IIOS). This procedure deals with the information provided in the IIOS on changes in inventories.

where  $x_{(g+1,s)}^{(1j)r}$  is the demand by sector  $j$  in region  $r$  for each primary factor;  $a_{(g+1,s)}^{(1j)r}$  is the exogenous sector-specific variable of (saving) technical change for primary factor  $s$  in region  $r$ ;  $p_{(g+1,s)}^{(1j)r}$  is the price paid by sector  $j$  in region  $r$  for primary factor  $s$ ;  $\sigma_{(g+1)}^{(1j)r}$  is a parameter measuring the sector-specific elasticity of substitution among different primary factors; and  $V(g+1, l, (1j), r)$  is an input-output flow coefficient that measures purchasers' value of factor  $l$  used by sector  $j$  in region  $r$ .

In this metropolitan framework, labor inputs are defined by the place of residence. Firms producing at a given region draw their workers from the labor force available in all the municipalities. Equation (4) defines the composition of industry  $j$ 's in region  $r$  labor input. In addition to the industry-region-specific expansion in the overall demand for labor, the demand for workers from different locations also respond to changes in the wage of each type relative to the average wage for labor in each regional industry. Notice that, in Equation (4), technical changes variables associated with labor by place of residence allow imposing productivity shocks that will relate to changes in commuting costs.

We model the combination of intermediate inputs and the value added (primary factors) aggregate in fixed proportions, at the very top of the nested production function, assuming there is no substitution between primary factors and other inputs. The Leontief specification is presented in Equation (5). More flexible functional forms have been rarely introduced in multi-regional models, mainly due to data availability constraints. In addition to a technical coefficient in the relation between the sectoral demand for the primary factor composite and the total output, we have also included a scale parameter. This modeling procedure has been based on previous work made by Haddad and Hewings (2005) which allows for the introduction of Marshallian agglomeration (external) economies, by exploring local properties of the CES function.

$$x_{(g+1(1b))}^{(1j)r} = x_{(g+1(1\cdot))}^{(1j)r} - \sigma_{(g+1(1\cdot))}^{(1j)r} (p_{(g+1(1b))}^{(1j)r} - \sum_{l \in S^*} (\frac{V(g+1, 1l, (1j), r)}{V(g+1, 1\cdot, (1j), r)}) (p_{(g+1(1l))}^{(1j)r}))$$

$$j \in H; i \in G; b \in S^*; r \in S^* \quad (4)$$

where  $x_{(g+1(1b))}^{(1j)r}$  is the demand by sector  $(1j)$  in region  $r$  for workers living in the domestic region (1b);  $p_{(g+1(1b))}^{(1j)r}$  is the wage paid by sector  $(1j)$  in region  $r$  for workers residing in the domestic region (1b);  $\sigma_{(g+1(1\cdot))}^{(1j)r}$  is a parameter measuring the sector-specific elasticity of substitution between workers living in different locations (1b); and  $V(g+1, 1l, (1j), r)$  is an input-output flow coefficient that measures labor payments for workers living in region (1b) made by firms producing in region  $r$ .

$$x_{(i\cdot)}^{(1j)r} = \mu_{(g+1,\cdot)}^{(1j)r} z_{(i\cdot)}^{(1j)r} + a_{(i\cdot)}^{(1j)r}$$

$$j \in H; i \in G^*; r \in S^* \quad (5)$$

where  $x_{(i\cdot)}^{(1j)r}$  is the demand by sector  $j$  in region  $r$  for the bundles of composite intermediate inputs and primary factors  $i$ ;  $z_{(i\cdot)}^{(1j)r}$  is total output of sector  $j$  in region  $r$ ;  $a_{(i\cdot)}^{(1j)r}$  is the exogenous sector-specific variable of technical change for composite intermediate inputs and primary factors in region  $r$ ; and  $\mu_{(i\cdot)}^{(1j)r}$  is a scale parameter measuring the sector-specific returns to the composite of primary factors in each region.

Units of capital stock are created for industry  $j$ , at minimum cost. Commodities are combined via a Leontief function, as specified in Equation (6). As described in Equations (1) and (2), regional, and domestic and imported commodities are combined, respectively, via a CES specification (Armington assumption). No primary factors are used in capital creation. The use of these inputs is recognized through the capital goods producing sectors in the model, mainly machinery and equipment industries, construction, and support services.

$$x_{(i\cdot)}^{(2j)r} = z_{(2j)r} + a_{(i\cdot)}^{(2j)r}$$

$$j \in H; i \in G; r \in S^* \quad (6)$$

where  $x_{(i\cdot)}^{(2j)r}$  is the demand by sector  $j$  in region  $r$  for the bundles of composite capital goods  $i$ ;  $z_{(2j)r}$  is total investment of sector  $j$  in region  $r$ ;  $a_{(i\cdot)}^{(2j)r}$  is the exogenous sector-specific variable of technical change for changing the composition of the sectoral unit of capital in region  $r$ .

In deriving the household demands for composite commodities, we assume that households in each region behave as a single, budget-constrained, utility-maximizing entity. The utility function is of the Stone-Geary or Klein-Rubin form. Equation (7) determines the optimal composition of household demand in each region. Total regional household consumption is determined as a function of real household income. The demands for the commodity bundles in the nesting structure of household demand follow the CES pattern established in Equations (1) and (2), in which an activity variable and a price-substitution term play the major roles. In Equation (7), consumption of each commodity  $i$  depends on two components: first, for the subsistence component, which is defined as the minimum expenditure requirement for each commodity, changes in demand are generated by changes in the number of households and tastes; second, for the luxury or supernumerary part of the expenditures in each good, demand moves with changes in the regional supernumerary expenditures, changes in tastes, and changes in the price of the composite commodity. The two components of household expenditures on the composite commodities are weighted by their respective shares in the total consumption of the composite commodity.

$$V(i, \cdot, (3), r) (p_{(i\cdot)}^{(3)r} + x_{(i\cdot)}^{(3)r} - a_{(i\cdot)}^{(3)r}) = \gamma_{(i)}^r p_{(i\cdot)}^{(3)r} Q^r (p_{(i\cdot)}^{(3)r} + x_{(i\cdot)}^{(3)r} - a_{(i\cdot)}^{(3)r}) + \beta_{(i)}^r (C^r - \sum_{j \in G} \gamma_{(j)}^r p_{(j\cdot)}^{(3)r} Q^r (p_{(j\cdot)}^{(3)r} + x_{(j\cdot)}^{(3)r} - a_{(j\cdot)}^{(3)r}))$$

$$i \in G; r \in S^* \quad (7)$$

where  $p_{(i\cdot)}^{(3)r}$  is the price paid by household in region  $r$  for the composite good  $i$ ;  $x_{(i\cdot)}^{(3)r}$  is the household demand in region  $r$  for the composite good  $i$ ;  $a_{(i\cdot)}^{(3)r}$  is the commodity-specific variable of regional taste change;  $Q^r$  is the number of households in region  $r$ ;  $C^r$  is the total expenditure by household in region  $r$ , which is proportional to regional labor income;  $\gamma_{(i)}^r$  is the subsistence parameter in the linear expenditure system for commodity  $i$  in region  $r$ ;  $\beta_{(i)}^r$  is the parameter defined for commodity  $i$  in region  $r$  measuring the marginal budget shares in the linear expenditure system; and  $V(i, \cdot, (3), r)$  is an input-output flow coefficient that measures purchasers' value of good  $i$  consumed by households in region  $r$ .

As noted by Peter et al. (1996), a feature of the Stone-Geary utility function is that only the above-subsistence, or luxury, component of real household consumption,  $utility^{(r)}$ , affects the per-household utility, as described in Equation (8).

$$utility^{(r)} = (C^r - \sum_{j \in G} \gamma_{(j)}^r p_{(j\cdot)}^{(3)r} Q^r (p_{(j\cdot)}^{(3)r} + x_{(j\cdot)}^{(3)r} - a_{(j\cdot)}^{(3)r})) - q^r - \sum_{i \in G} \beta_{(i)}^r p_{(i\cdot)}^{(3)r}$$

$$r \in S^* \quad (8)$$

where  $q^r$  is the percentage change in the number of households in each region.

In Equation (9), foreign demands (exports) for domestic good  $i$  depend on the percentage changes in a price, and three shift variables which allow for vertical and horizontal movements in the demand curves. The price variable which influences export demands is the purchaser's price in foreign countries, which includes the relevant taxes and margins. The parameter  $\eta_{(is)}^r$  controls the sensitivity of export demand to price changes.

$$(x_{(is)}^{(4)r} - f_{(is)}^{(4)r}) = \eta_{(is)}^r (p_{(is)}^{(4)r} - phi - fp_{(is)}^{(4)r}) \quad (9)$$

where  $x_{(is)}^{(4)r}$  is foreign demand for domestic good  $i$  produced in region  $s$  and sold from region  $r$  (in the model there is no re-exports, so that  $r = s$ );  $p_{(is)}^{(4)r}$  is the purchasers' price in domestic currency of exported good  $i$  demand in region  $r$ ;  $phi$  is the nominal exchange rate; and  $f_{(is)}^{(4)r}$  and  $fp_{(is)}^{(4)r}$  are, respectively, quantity and price shift variables in foreign demand curves for regional exports.

Governments consume mainly public goods provided by the public administration sectors. Equation (10) shows the movement of government consumption in relation to movements in real tax revenue.

$$x_{(is)}^{(5)r} = taxrev + f_{(is)}^{(5)r} + f^{(5)r} + f^{(5)} \quad (10)$$

where  $x_{(is)}^{(5)r}$  is the government demand in region  $r$  for good  $i$  from region  $s$ ;  $f_{(is)}^{(5)r}$ ,  $f^{(5)r}$  and  $f^{(5)}$  are, respectively, commodity and source-specific shift term for government expenditures in region  $r$ , shift term for government expenditures in region  $r$ , and an overall shift term for government expenditures; and  $taxrev$  is the percentage change in real revenue from indirect taxes.

Equation (11) specifies the sales tax rates for different users. They allow for variations in tax rates across commodities, and their sources and destinations. Tax changes are expressed as percentage-point changes in the *ad valorem* tax rates.

$$t_{(is)}^{(u)r} = f_i + f_i^{(u)} + f_i^{(u)r} \quad (11)$$

where  $t_{(is)}^{(u)r}$  is the power of the tax on sales of commodity (is) to user (u) in region  $r$ ; and  $f_i$ ,  $f_i^{(u)}$ , and  $f_i^{(u)r}$  are different shift terms allowing percentage changes in the power of tax.

Equations (12) and (13) impose the equilibrium conditions in the domestic and imported commodities markets. Notice that there is no margin commodity in the model. Moreover, there is no secondary production in the model. In Equation (11), demand equals supply for regional domestic commodities.

$$\sum_{j \in H} Y(l, j, r) x_{(li)}^{(0)r} = \sum_{(u) \in U} B(l, 1b, (u), r) x_{(li)}^{(u)r} \quad (12)$$

where  $x_{(li)}^{(0)r}$  is the output of domestic good  $l$  by industry  $j$  in region  $r$ ;  $x_{(li)}^{(u)r}$  is the demand of the domestic good  $l$  by user (u) in region  $r$ ;  $Y(l, j, r)$  is the input-output flow measuring the basic value of output of domestic good  $l$  by industry  $j$  in region  $r$ ; and  $B(l, 1, (u), r)$  is the input-output flow measuring the basic value of domestic good  $l$  used by (u) in region  $r$ .

Equation (13) imposes zero pure profits in importing. It defines the basic price of a unit of imported commodity  $i$  – the revenue earned per unit by the importer – as the international C.I.F. price converted to domestic currency, including import tariffs.

$$p_{(i(2))}^{(0)} = p_{(i(2))}^{(w)} - phi + t_{(i(2))}^{(0)} \quad (13)$$

where  $p_{(i(2))}^{(0)}$  is the basic price in domestic currency of good  $i$  from foreign source;  $p_{(i(2))}^{(w)}$  is world C.I.F. price of imported commodity  $i$ ;  $phi$  is the nominal exchange rate; and  $t_{(i(2))}^{(0)}$  is the power of the tariff. i.e. one plus the tariff rate, on imports of  $i$ .

Together with Equation (13), Equations (14) and (15) constitute the model's pricing system. The price received for any activity is equal to the costs per unit of output. As can be noticed, the assumption of constant returns to scale adopted here precludes any activity variable from influencing basic prices, i.e., unit costs are independent of the scale at which activities are conducted. Thus, Equation (14) defines the percentage change in the price received by producers in regional industry  $j$  per unit of output as being equal to the percentage change in  $j$ 's costs, which are affected by changes in technology and changes in input prices.

$$\sum_{l \in G} Y(l, j, r) (p_{(li)}^{(0)r} + a_{(li)}^{(0)r}) = \sum_{l \in G^*, F} \sum_{s \in S} V(l, s, (1j), r) p_{(ls)}^{(1j)r} \quad (14)$$

where  $p_{(li)}^{(0)r}$  is the basic price of domestic good  $l$  in region  $r$ ;  $a_{(li)}^{(0)r}$  refer to technological changes, measured as a weighted average of the different types of technical changes with influence on  $j$ 's unit costs;  $p_{(ls)}^{(1j)r}$  is the unit cost of sector  $j$  in region  $r$ ;  $Y(l, j, r)$  is the input-output flow measuring the basic value of output of domestic good  $l$  by industry  $j$  in region  $r$ ; and  $V(l, s, (1j), r)$  are input-output flows measuring purchasers' value of good or factor  $l$  from source  $s$  used by sector  $j$  in region  $r$ .

Equation (15) imposes zero pure profits in the distribution of commodities to different users. Prices paid for commodity  $i$  from region  $s$  in industry  $j$  in region  $r$  by each user equate to the sum of its basic value and the costs of the relevant taxes.

$$V(i, s, (u), r) p_{(is)}^{(u)r} = (B(i, s, (u), r) + T(i, s, (u), r)) (p_{(is)}^{(0)} + t_{(is)}^{(u)r})$$

$$i \in G; s = 1b, 2; b, r \in S^*; u \in U \quad (15)$$

where  $p_{(is)}^{(u)r}$  is the price paid by user ( $u$ ) in region  $r$  for good ( $is$ );  $p_{(is)}^{(0)}$  is the basic price of domestic good ( $is$ );  $t_{(is)}^{(u)r}$  is the power of the tax on sales of commodity ( $is$ ) to user ( $u$ ) in region  $r$ ;  $V(i, s, (u), r)$  are input-output flows measuring purchasers' value of good  $i$  from source  $s$  used by user ( $u$ ) in region  $r$ ;  $B(i, s, (u), r)$  is the input-output flow measuring the basic value of good ( $is$ ) used by ( $u$ ) in region  $r$ ; and  $T(i, s, (u), r)$  is the input-output flow associated with tax revenue of the sales of ( $is$ ) to ( $u$ ) in region  $r$ .

The theory of the allocation of investment across industries is represented in Equations (16)–(19). The comparative-static nature of the model restricts its use to short-run and long-run policy analysis. When running the model in the comparative-static mode, there is no fixed relationship between capital and investment. The user decides the required relationship on the basis of the requirements of the specific simulation. Equation (16) defines the percentage change in the current rate of return on fixed capital in regional sectors. Under static expectations, rates of return are defined as the ratio between the rental values and the cost of a unit of capital in each industry – defined in Equation (17) –, minus the rate of depreciation.

$$r_{(j)}^r = \psi_{(j)}^r (p_{(g+1,2)}^{(1j)r} - p_{(k)}^{(1j)r}) \quad (16)$$

$$j \in H; r \in S^*$$

where  $r_{(j)}^r$  is the regional-industry-specific rate of return;  $p_{(g+1,2)}^{(1j)r}$  is the rental value of capital in sector  $j$  in region  $r$ ;  $p_{(k)}^{(1j)r}$  is the cost of constructing units of capital for regional industries; and  $\psi_{(j)}^r$  is a regional-industry-specific parameter referring to the ratio of the gross to the net rate of return.

Equation (17) defines  $p_{(k)}^{(1j)r}$  as:

$$V(\bullet, \bullet, (2j), r)(p_{(k)}^{(1j)r} - a_{(k)}^{(1j)r}) = \sum_{i \in G} \sum_{s \in S} V(i, s, (2j), r)(p_{(is)}^{(2j)r} - a_{(is)}^{(2j)r}) \quad (17)$$

$$j \in H; r \in S^*$$

where  $p_{(is)}^{(2j)r}$  is the price paid by user ( $2j$ ) in region  $r$  for good ( $is$ );  $a_{(k)}^{(1j)r}$  and  $a_{(is)}^{(2j)r}$  are technical terms; and  $V(i, s, (2j), r)$  represents input-output flows measuring purchasers' value of good  $i$  from source  $s$  used by user ( $2j$ ) in region  $r$ .

Equation (18) says that if the percentage change in the rate of return in a regional industry grows faster than the national average rate of return, capital stocks in that industry will increase at a higher rate than the average national stock. For industries with lower-than-average increase in their rates of return to fixed capital, capital stocks increase at a lower-than-average rate, i.e., capital is attracted to higher return industries. The shift variable,  $f_{(k)}^{(1j)r}$ , exogenous in long-run simulation, allows shifts in the industry's rates of return.

$$r_{(j)}^r - \omega = \varepsilon_{(j)}^r (x_{(g+1,2)}^{(1j)r} - x_{(g+1,2)}^{(\bullet)r}) + f_{(k)}^{(1j)r} \quad (18)$$

$$j \in H; r \in S^*$$

where  $r_{(j)}^r$  is the regional-industry-specific rate of return;  $\omega$  is the overall rate of return on capital;  $x_{(g+1,2)}^{(1j)r}$  is the capital stock in industry  $j$  in region  $r$ ;  $f_{(k)}^{(1j)r}$  the capital shift term in sector  $j$  in region  $r$ ; and  $\varepsilon_{(j)}^r$  measures the sensitivity of capital growth to rates of return of industry  $j$  in region  $r$ .

Equation (19) implies that the percentage change in an industry's capital stock,  $x_{(g+1,2)}^{(1j)r}$ , is equal to the percentage change in industry's investments in the period,  $z^{(2j)r}$ .

$$z^{(2j)r} = x_{(g+1,2)}^{(1j)r} + f_{(k)}^{(2j)r} \quad (19)$$

$$j \in H; r \in S^*$$

where  $f_{(k)}^{(2j)r}$  allows for exogenous shifts in sectoral investments in region  $r$ .

In the specification of the labor market, Equation (20) defines the regional aggregation of labor prices (wages) across industries by place of production while Equation (21) defines aggregate wages by place of residence. Equation (22) shows movements in regional wage differentials,  $wage\_diff^{(r)}$ , defined as the difference between the movement in the aggregate regional real wage received by workers in region  $r$ , and the national real wage.

$$V(g+1, 1b, \bullet, r)(p_{(g+1,1\bullet)}^{(\bullet)r} - a_{(g+1,1\bullet)}^{(\bullet)r}) = \sum_{b \in S^*} \sum_{j \in H} V(g+1, 1b, (1j), r)(p_{(g+1,1b)}^{(1j)r} - a_{(g+1,1b)}^{(1j)r}) \quad (20)$$

$$r \in S^*$$

$$V(g+1, 1b, \bullet, \bullet)(p_{(g+1,1b)}^{(\bullet)\bullet} - a_{(g+1,1b)}^{(\bullet)\bullet}) = \sum_{r \in S^*} \sum_{j \in H} V(g+1, 1b, (1j), r)(p_{(g+1,1b)}^{(1j)r} - a_{(g+1,1b)}^{(1j)r}) \quad (21)$$

$$b \in S^*$$

where  $p_{(g+1,1\bullet)}^{(\bullet)r}$  is the wage in sector  $j$  in region  $r$ ,  $a_{(g+1,1\bullet)}^{(\bullet)r}$  is a technical term, and  $V(g+1, 1b, (1j), r)$  represents input-output flows measuring sectoral labor payments to residents in region  $1b$  working in region  $r$ .

$$wage\_diff^{(r)} = p_{(g+1,1r)}^{(\bullet)\bullet} - cpi - natrealwage \quad (22)$$

$$r \in S^*$$

where  $cpi$  is the national consumer price index, computed as the weighted average of  $p_{(is)}^{(3)r}$  across regions  $r$  and consumption goods ( $is$ ); and  $natrealwage$  is the national consumer real wage.

Regional population is defined through the interaction of demographic variables, including interregional migration. Links between regional population and regional labor supply are provided. Demographic variables are usually defined exogenously, and together with the specification of some of the labor market settings, labor supply can be determined together with either interregional wage differentials or regional unemployment rates. In summary, either labor supply and wage differentials determine unemployment rates, or labor supply and unemployment rates determine

wage differentials.

Equation (23) defines the percentage-point change in regional unemployment rates in terms of percentage changes in labor supply and persons employed.

$$\begin{aligned} LABSUP(r)del\_unr^{(r)} &= EMPLOY(r)(labsup^{(r)} - x_{(g+1,1r)}^{(\cdot)}) \\ r &\in S^* \end{aligned} \quad (23)$$

where  $del\_unr^{(r)}$  measures percentage-point changes in regional unemployment rate;  $labsup^{(r)}$  is the variable for regional labor supply; and the coefficients  $LABSUP(r)$  and  $EMPLOY(r)$  are the benchmark values for regional labor supply and regional employment, respectively, measured in terms of the resident population in the region. The variable  $labsup^{(r)}$  moves with regional workforce participation rate, proportional to the regional population, and population of working age. Equation (24) defines regional population changes in the model as ordinary changes in flows of net regional migration ( $d\_rm^{(r)}$ ), net foreign migration ( $d\_fm^{(r)}$ ), and natural population growth ( $d\_g^{(r)}$ ).

$$\begin{aligned} POP(r)pop^{(r)} &= d\_rm^{(r)} + d\_fm^{(r)} + d\_g^{(r)} \\ r &\in S^* \end{aligned} \tag{24}$$

where  $POP(r)$  is a coefficient measuring regional population in the benchmark year.

Equation (25) shows movements in per-household utility differentials,  $util\_diff^{(r)}$ , defined as the difference between the movement in regional utility, and the national overall utility ( $agg\_util$ ), including a shift variable,  $futil^{(r)}$ .

$$\begin{aligned} util\_diff^{(r)} &= utility^{(r)} - agg\_util + futil^{(r)} \\ r &\in S^* \end{aligned} \tag{25}$$

Finally, we can define changes in regional output as weighted averages of changes in regional aggregates, according to Equation (26) below:

$$GRPrgrpr = C^r x_{(\bullet\bullet)}^{(3)r} + INV^r z^{(2\bullet)r} + GOV^r x_{(\bullet\bullet)}^{(5)r} + (FEXP^r x_{(\bullet\bullet)}^{(4)r} - FIMP^r x_{(\bullet 2)}^{(\bullet)r}) + (DEXP^r x_{(\bullet(1r))}^{(\bullet)s} - DIMP^r x_{(\bullet(1s))}^{(\bullet)r})$$

$$r \in S^*; s \in S^* \text{ for } s \neq r \quad (26)$$

where  $grp^r$  is the percentage change in real Gross Regional Product in region  $r$ ; and the coefficients  $GRP^r INV^r$ ,  $GOV^r$ ,  $FEXP^r$ ,  $FIMP^r$ ,  $DEXP^r$  and  $DIMP^r$  represent, respectively, the following regional aggregates: investments, government spending, foreign exports, foreign imports, domestic exports and domestic imports. National output,  $GDP$ , is, thus, the sum of  $GRP^r$  across all regions  $r$ . Notice that regional domestic trade balances cancel out.

To close the model, we set the following variables exogenously, which are usually exogenous both in short run and long run simulations:  $a_{(g+1,s)}^{(ij)r}$ ,  $a_{(i)}^{(1j)r}$ ,  $a_{(i)}^{(2j)r}$ ,  $a_{(is)}^{(3)r}$ ,  $fq_{(is)}^{(4)r}$ ,  $fp_{(is)}^{(4)r}$ ,  $f_{(is)}^{(5)r}$ ,  $f^{(5)r}$ ,  $f_i^{(w)}$ ,  $f_i^{(u)r}$ ,  $p_{(i(2))}^{(w)}$ ,  $t_{(i(2))}^{(0)}$ ,  $a_{(i1)}^{(0)r}$ ,  $a_{(k)}^{(1j)r}$ ,  $a_{(is)}^{(2j)r}$ ,  $a_{(g+1,1b)}^{(*)r}$ ,  $\omega$ ,  $f_{(k)}^{(2j)r}$ ,  $d\_fm^{(r)}$ ,  $d\_g^{(r)}$ , and  $futil^{(r)}$ . To complete the short run environment, used in our forthcoming exercises, we also set unchanged current stocks of capital ( $x_{(g+1,2)}^{(1j)r}$ ), the national real wage ( $natrealwage$ ), regional wage differentials, ( $wage\_diff^{(r)}$ ), and regional population, by keeping regional migration unchanged ( $d\_rm^{(r)}$ ).<sup>14</sup>

There are other definitions of variables computed by using outcomes from simulations based on the system of equations (1)-(26).

## Calibration

The calibration of the model requires two subsets of data to define its numerical structure so that we implement the model empirically. First, we need information from an absorption matrix derived from interregional input-output sources (Table A2.1) to calculate the coefficients of the model based on the following input-output flows:

- $B(i, 1b, (u), r)$ , with  $i \in G^*$ ,  $(u) \in U$ ,  $b, r \in S^*$
- $T(i, s, (u), r)$ , with  $i \in G^*$ ,  $s \in S$ ,  $(u) \in U$ ,  $r \in S^*$
- $V(i, s, (u), r)$ , with  $i \in G^*$ ,  $s \in S, F$ ,  $(u) \in U$ ,  $r \in S^*$
- $Y(i, j, r)$ , with  $i \in G^*$ ,  $j \in H$ ,  $r \in S^*$

- $T(i, s, (u), r)$ , with  $i \in G^*$ ,  $s \in S$ ,  $(u) \in U$ ,  $r \in S^*$

- $V(i, s, (u), r)$ , with  $i \in G^*$ ,  $s \in S, F$ ,  $(u) \in U$ ,  $r \in S^*$

- $Y(i, j, r)$ , with  $i \in G^*$ ,  $j \in H$ ,  $r \in S^*$

We complete this information with supplementary demographic data from IBGE to calibrate the coefficients  $LABSUP(r)$ ,  $EMPLOY(r)$  and  $POP(r)$ , with  $r \in S^*$ . Because these estimates are based on snapshot observations for a single year revealing the economic structure of the economic system, this subset of data is denoted “structural coefficients” (Haddad et al., 2015).

The second piece of information necessary to calibrate the model is represented by the subset of data defining various parameters, mainly elasticities. These are called “behavioral parameters”. Empirical estimates for some of the parameters of the model are not available in the literature. We have thus relied on “best guesstimates” based on usual values employed in similar models. We set to 1.5 the values for both regional trade elasticities,  $\sigma_{(i)}^{(u)r}$  in Equation (1) and international trade elasticities,  $\sigma_{(i)}^{(u)r}$  in Equation (2). Substitution elasticity between primary factors,  $\sigma_{(g+1)}^{(1)r}$  in Equation (3), was set to 0.5, and substitution elasticity between labor types,  $\sigma_{(g+1)}^{(1)r}$  in Equation (4), was set to 0.05. The current version of the model runs under constant returns to scale, so that we set to 1.0 the values of  $\mu_{(g+1)}^{(1)r}$  in Equation (5). The marginal budget shares in regional household consumption,  $\beta_{(i)}^r$  in Equation (7), were calibrated from the input-output data, assuming the average budget share to be equal to the marginal budget share, and the subsistence parameter  $\gamma_{(i)}^r$ , also in Equation (7), was associated with a Frisch parameter equal to  $-3.7$ . We have set to  $-2.0$  the export demand elasticities,  $\eta_{(is)}^r$  in Equation (9). The ratio of gross to net rate of return,  $\psi_{(i)}^r$  in Equation (16), was set to 1.2. Finally, we set to 3.0 the parameter for sensitivity of capital growth to rates of return,  $\varepsilon_{(i)}^r$  in Equation (18).

<sup>14</sup> In a long run closure, the assumptions on interregional mobility of capital and labor are relaxed by swapping variables  $x_{(g+1,2)}^{(1)r}$ , *natrealwage*, *wage\_diff*<sup>(r)</sup> and *d\_rm*<sup>(r)</sup>, for  $f_{(k)}^{(1)r}$ , *del\_unr*<sup>(r)</sup> and *util\_diff*<sup>(r)</sup>.a.



Table A2.1

Aggregate Flows in the Absorption Matrix: SPMR, 2008.  
(values in current BRL millions).

LABELS	User (1j) <sup>r</sup>	User (2j) <sup>r</sup>	User (3) <sup>r</sup>	User (4)	User (5) <sup>r</sup>	User (6)	TOTAL
$i \in G, s \in S^*$	$B(i, 1b, (1j), r)$	$B(i, 1b, (2j), r)$	$B(i, 1b, (3), r)$	$B(i, 1b, (4))$	$B(i, 1b, (5), r)$	$B(i, 1b, (6))$	$B(i, 1b, (\cdot), \cdot)$
$i \in G, s \in S-S^*$	$B(i, 2, (1j), r)$	$B(i, 2, (2j), r)$	$B(i, 2, (3), r)$	$B(i, 2, (4))$	$B(i, 2, (5), r)$	$B(i, 2, (6))$	$B(i, 2, (\cdot), \cdot)$
$i \in G, s \in S$	$T(i, s, (1j), r)$	$T(i, s, (2j), r)$	$T(i, s, (3), r)$	$T(i, s, (4))$	$T(i, s, (5), r)$	–	$T(i, s, (\cdot), \cdot)$
$s \in F$	$V(g + 1, s, (1j), r)$	–	–	–	–	–	$V(g + 1, s, (\cdot), \cdot)$
TOTAL	$Y(\cdot, \cdot, r)$	$V(\cdot, \cdot, (2j), r)$	$V(\cdot, \cdot, (3), r)$	$V(\cdot, \cdot, (4))$	$V(\cdot, \cdot, (5), r)$	–	$V(\cdot, \cdot, (\cdot), \cdot)$
BRL	User (1j) <sup>r</sup>	User (2j) <sup>r</sup>	User (3) <sup>r</sup>	User (4)	User (5) <sup>r</sup>	User (6)	TOTAL
$i \in G, s \in S^*$	22,66,060	4,73,957	15,03,559	4,56,070	5,90,814	17,931	53,08,391
$i \in G, s \in S-S^*$	2,60,324	63,950	87,709	0	0	6391	4,18,374
$i \in G, s \in S$	2,02,128	41,624	1,60,585	24,791	0	2517	4,31,645
$s \in F$	25,79,879	–	–	–	–	–	25,79,879
TOTAL	53,08,391	5,79,531	17,51,853	4,80,861	5,90,814	26,839	87,38,289

### Appendix 3. Definition of investments and policy scenarios

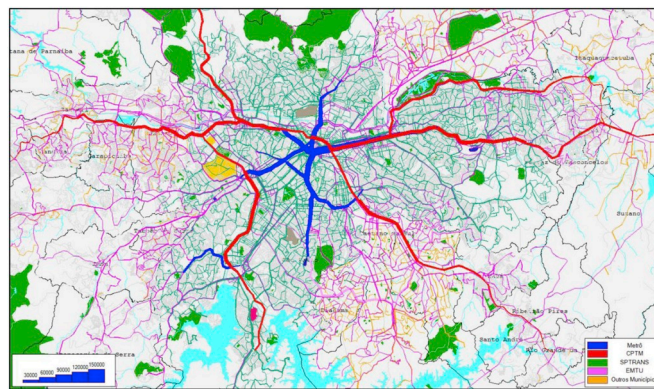


Fig. A3.1. Current Public Transportation Network (transit volumes).

Source: TTC.

Plans for future railway network were obtained from Metro and CPTM, and show the planned expansion of metro, train and monorail in the SPMR for years 2020 and 2025. Based on these data, the implementation schedule presented by the government was compared with the history of construction and opening of railway lines, in order to establish an implementation schedule as realistic as possible, to be used in the analysis (details in Figs. A3.2-A3-3 and Tables A3.1-A3.4).

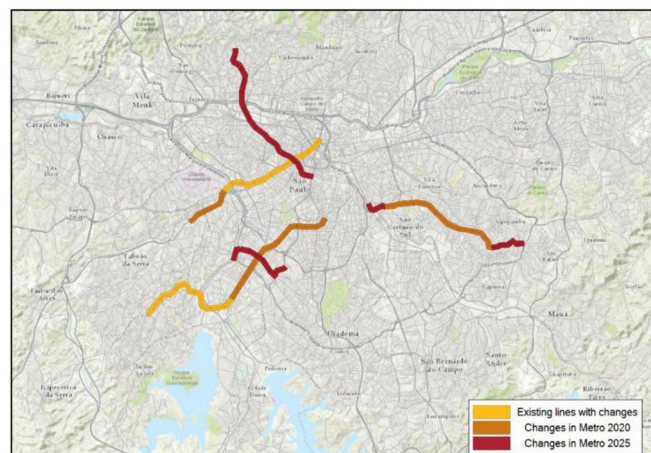


Fig. A3.2. Planned Extensions of Metro.

Source: TTC.



Table A3.1  
Changes in Metro network until 2020  
Source: TTC.

Line	Path	Plus extension (km)
Line 4 - Yellow	Vila Sônia - Luz	3.8
Line 5 - Lilac	Capão Redondo - Chácara Klabin	9.9
Line 15 - Silver	Vila Prudente - Sapopemba	9.3
TOTAL		23.0

Table A3.2  
Changes in Metro network until 2025.  
Source: TTC.

Line	Path	Plus extension (km)
Line 4 - Yellow	Vila Sônia - Luz	3.8
Line 5 - Lilac	Capão Redondo - Chácara Klabin	9.9
Line 6 - Orange	Brasilândia - São Joaquim	13.5
Line 15 - Silver	Ipiranga - São Mateus	12.1
Line 17 - Gold	Jardim Aeroporto - Congonhas - Morumbi (L9)	6.7
TOTAL		46.0

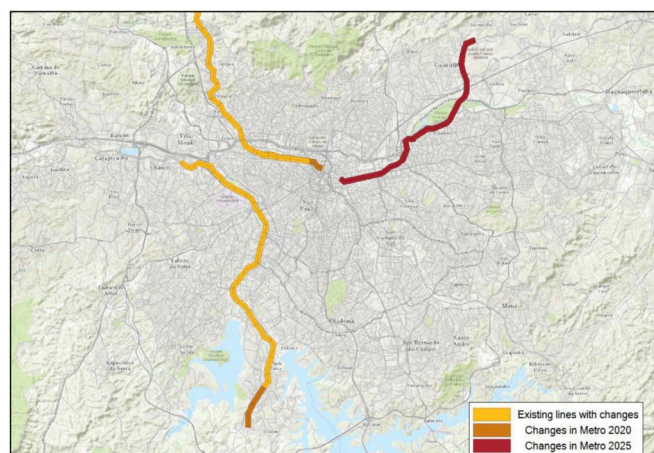


Fig. A3.3. Planned Extensions of Urban Rail (CPTM).  
Source: TTC.

Table A3.3  
Changes in Urban Trains (CPTM) network until 2020.  
Source: TTC

Line	Path	Plus extension (km)
Line 7 - Ruby	Francisco Morato - Bom Retiro	2.1
Line 8 - Diamond	Itapevi - Bom Retiro	2.1
Line 9 - Emerald	Varginha - Osasco	4.2
TOTAL		8.4

Table A3.4  
Changes in Urban Trains (CPTM) network until 2025.  
Source: TTC

Line	Path	Plus extension (km)
Line 7 - Ruby	Francisco Morato - Bom Retiro	2.1

(continued on next page)

Table A3.4 (continued)

Line	Path	Plus extension (km)
Line 8 - Diamond	Itapevi - Bom Retiro	2.1
Line 9 - Emerald	Varginha - Osasco	4.2
Line 13 - Jade	Aeroporto - Brás	24.9
TOTAL		33.3

Expansion plans for the bus network of São Paulo come from the investment plans on corridors collected from São Paulo Transportation – SPTrans (see Fig. A3.4). As it was done for the case of the rail system, a comparison with the historical implementation schedule was used to adjust the planned schedule to a more realistic implementation plan. This adjusted schedule is presented in the figure and tables included below (Fig. A3.4 and Tables A3.5–A3.6).

For bus corridors implemented on existing roads where the road hierarchy remained unchanged, the changes in the simulation were limited to increases in commercial speeds over the line on said link, untying such speed to the speed of the general traffic. Further, for bus corridors implemented on new roads or in roads where the functional hierarchy was changed, adjustments on the itineraries of routes were made so as to account for the new connections in addition to the adjustments made to speed.

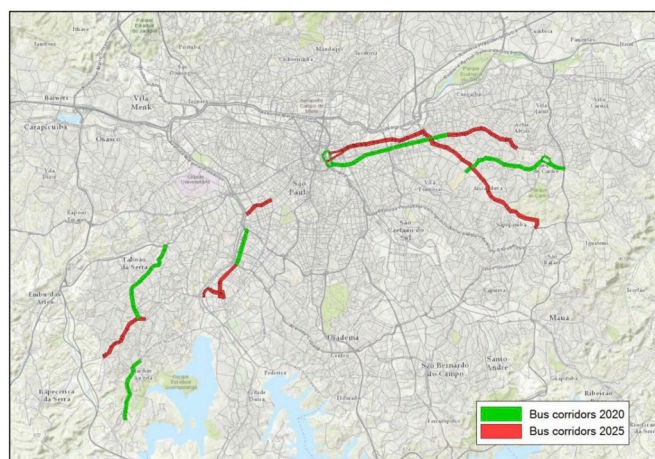


Fig. A3.4. Planned Extensions of Rapid Bus Lanes.

Source: TTC.

Table A3.5

Changes in bus corridors until 2020.

Source: TTC.

Corridor	Main roads	Plus extension (km)
Berrini	Av. Berrini (Trecho 1)	3.6
Campo Limpo (Capelinha - V. Sônia)	Av. Carlos Lacerda/Estr. Campo Limpo/Av. Fco. Morato	12.2
Itaquera - Líder	Av. Itaquera/Av. Líder/Rua São Teodoro)	10.4
Radial Leste	Av. Alcantara Machado/R. Melo Freire (Trecho 1)	9.9
M'Boi Mirim	Estr. M'Boi Mirim (extensão)	5.3
TOTAL		41.5

Table A3.6

Changes in bus corridors until 2025.

Source: TTC.

Corridor	Main roads	Plus extension (km)
Aricanduva	Av. Aricanduva	13.7
Berrini	Av. Berrini (Trecho 1)	3.6
Berrini	Av. Chucuri Zaidan/viário novo (Trecho 2)	3.5
Campo Limpo (Capelinha - V. Sônia)	Av. Carlos Lacerda/Estr. Campo Limpo/Av. Fco. Morato	12.2
Nove de Julho - Santo Amaro	Av. Cidade Jardim (extensão)	2.2
Itaquera - Líder	Av. Itaquera/Av. Líder/Rua São Teodoro)	10.4
Ponte Baixa	Rua Antonio Aranha/Av. Tomás do Vale/viário novo	4.6

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Table A3.6 (continued)

Corridor	Main roads	Plus extension (km)
Radial Leste	Av. Alcantara Machado/R. Melo Freire (Trecho 1)	9.9
Radial Leste	Av. Luiz Ayres (Trecho 2)	7.1
Celso Garcia - São Miguel	Av. Celso Garcia/até Penha (Trecho 2)	9.5
Itapecerica	Estr. de Itapecerica (extensão)	4.5
M'Boi Mirim	Estr. M'Boi Mirim (extensão)	5.3
TOTAL		86.5

To estimate the impacts of the implementation of an urban toll in the city of São Paulo, the expanded center of the city was used to define the CBD, which outlined the area for which the toll would be charged. Such area is identified by the shaded area within the red line in Fig. A3.5 below. This area is known as “expanded center” of São Paulo, and currently traffic restriction program (which only allows vehicles whose license numbers end with certain digits to drive on particular weekdays). The toll is assumed to be charged to all cars driving into the restricted area. Further, all trips originating within the area will pay the toll at the origin link, while trips beginning outside the area will pay the fare at the first link of the restricted area.

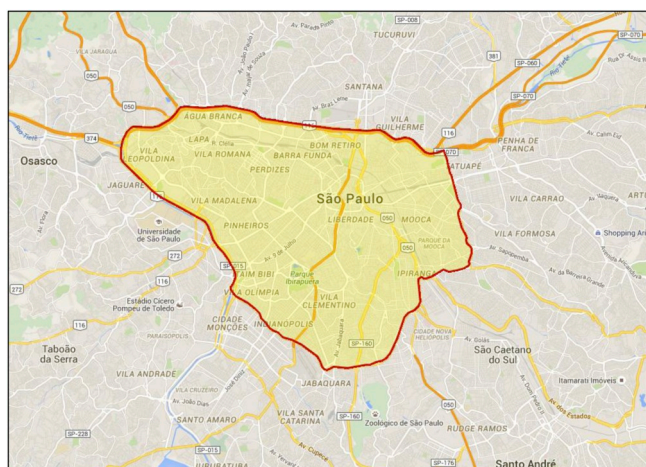


Fig. A3.5. São Paulo Extended CBD.

Source: CET.SP – Companhia de Engenharia de Tráfego de São Paulo.

Finally, the scenario where parking costs increase leads to increases in overall transportation costs as parking costs by region are used for the calculation of generalized transportation costs matrices. The average cost of parking in the trip destination zone is considered in the generalized costs travel to that area, therefore affecting the decision of travelers to go to that area. The average parking cost per destination is calculated as a weighted average of the prices of that area by the number of trips that use parking. Thus, areas with few trips using parking has average costs of travel greatly reduced by trips that do not pay for parking.

Data from the OD/2007 survey suggest that only 8.3% of SPMR car trips pay for parking (Table A3.7). Fig. A3.6 shows the proportion of trips that pay for parking. Among those paying are users of the Blue Zone (similar to a parking meter), public parking lot users paying by the hour and monthly users. Among the non-paying are those using curb side parking, own parking spaces, sponsored (parking available at no cost) and those who do not park at all. Further, only car trips for work/study are included in the calculation, disregarding the trips made to drop another person to a destination. Trips using paid parking overnight at the residence location were also excluded from the simulation.

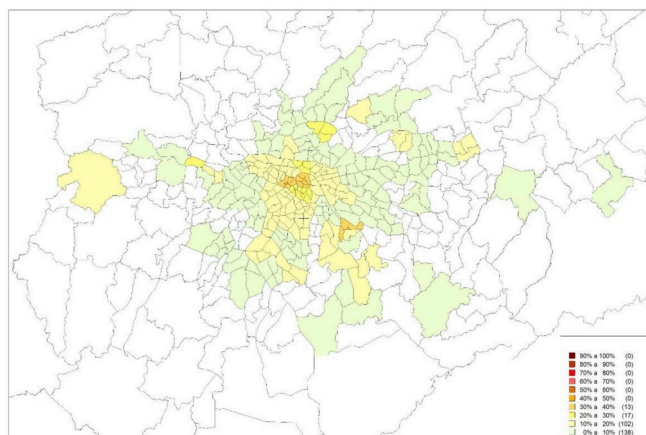


Fig. A3.6. Percentage of trips that pay for parking.

Source: TTC.

Proportion of trips paying for parking by area (%)				
Type	Category	MRSP	Expanded center	Center
Blue zone	Paying	0.7%	1.7%	2.4%
Parking lot (hourly+monthly)	Paying	7.6%	15.2%	22.6%
<b>Paying for parking</b>		<b>8.3%</b>	<b>16.9%</b>	<b>25.1%</b>
<b>Weighted average costs for parking</b>		<b>\$ 0.70</b>	<b>\$ 0.93</b>	<b>\$ 1.11</b>
Sponsored parking lot	Not paying	52.9%	48.7%	46.4%
Own parking	Not paying	11.9%	9.5%	9.0%
Curb parking	Not paying	25.4%	23.9%	18.3%
Not parking	Not paying	1.5%	1.1%	1.2%
<b>Not paying for parking</b>		<b>91.7%</b>	<b>83.1%</b>	<b>74.9%</b>
<b>Total of trips</b>		<b>21,81,308</b>	<b>6,52,478</b>	<b>1,79,530</b>

Table A3.7. Proportion of average auto trips by parking type.

Source: TTC.

Table A3.8 below summarizes the impacts on generalized costs and number of auto and transit trips for each scenario.

Table A3.8

Summary results per scenario.

Source: TTC.

Scenario	Auto generalized costs (min)	Var. (%)	Transit generalized costs (min)	Var. (%)	Auto trips	Transit trips	Percentage of transit trips (%)
Scenario 0	4,93,93,784	–	5,10,55,637	–	12,11,347	16,05,276	57.0%
Scenario 1	4,93,46,714	– 0.1%	4,86,45,136	– 4.7%	12,11,951	16,04,674	57.0%
Scenario 2	4,92,93,780	– 0.2%	4,85,10,714	– 5.0%	12,10,189	16,06,436	57.0%
Scenario 3	4,91,68,278	– 0.5%	4,76,26,573	– 6.7%	12,03,601	16,13,022	57.3%
Scenario 4	4,90,28,855	– 0.7%	4,74,42,580	– 7.1%	12,00,579	16,16,044	57.4%
Scenario 5	5,77,05,139	16.8%	4,71,74,920	– 7.6%	10,97,304	17,19,319	61.0%
Scenario 6	5,83,51,603	18.1%	5,06,00,088	– 0.9%	11,18,669	16,97,954	60.3%
Scenario 7	5,81,95,915	17.8%	5,08,79,975	– 0.3%	11,14,858	17,01,766	60.4%
Scenario 8	4,90,97,676	– 0.6%	5,08,96,886	– 0.3%	11,82,994	16,33,630	58.0%
Scenario 9	4,90,21,173	– 0.8%	5,09,21,652	– 0.3%	11,92,138	16,24,486	57.7%
Scenario 10	4,91,19,771	– 0.6%	5,07,86,838	– 0.5%	11,58,818	16,57,807	58.9%

The result suggest that the most significant change toward mass transit modes is seen in scenarios 5,6, and 7 as these implement restrictions to auto use. The fact that scenarios 1 through 4 are not reflecting the largest changes of transportation mode confirms the well-known fact that supply side efforts are not enough to encourage users to move to mass transportation modes.

## References

- Cao, X., Pan, Q., 2016. Editorial: Rapid transit and land development in a diverse world. *Transport Pol.* 51, 1–3.
- Clarke, M., Holm, M., 1987. Microsimulation methods in spatial analysis and planning. *Geogr. Ann. B* 69, 145–164.
- Fernald, John G., 1999. Roads to Prosperity? Assessing the link between public capital and productivity. *Am. Econ. Rev.* 89 (3), 619–638.
- Ghani, E., Goswami, A.G., Kerr, W.R., 2012. Is India's Manufacturing Sector Moving Away from Cities? NBER Working Paper No. 17992, April.
- Gobillon, L., Selod, H., 2014. Spatial mismatch, poverty, and vulnerable populations. In: Fischer, M.M., Nijkamp, P. (Eds.), *Handbook of Regional Science*. Springer.
- Gobillon, L., Selod, H., Zenou, Y., 2007. The mechanisms of spatial mismatch. *Urban Stud.* 44 (No. 12), 2401–2427.
- Haddad, E.A., Barufi, A.M.B., 2017. From rivers to roads: spatial mismatch and inequality of opportunity in urban labor markets of a megacity. *Habitat Int.* 68, 3–14. <https://doi.org/10.1016/j.habitatint.2017.03.016>.
- Haddad, E.A., Hewings, G.J.D., Porsse, A.A., Van Leeuwen, E.S., Vieira, R.S., 2015. The underground economy: tracking the wider impacts of the São Paulo subway system. *Transport. Res. Pol. Pract.* 73, 18–30.
- Haddad, E.A., Hewings, G.J.D., 2005. Market imperfections in a spatial economy: some experimental results. *Q. Rev. Econ. Finance* 45, 476–496.
- Kim, E., Hewings, G.J.D., Hong, C., 2004. An application of integrated transportation network –multiregional CGE model I: a framework for economic analysis of highway project. *Econ. Syst. Res.* 16, 235–258.
- Melo, P.C., Graham, D.J., 2009. Agglomeration Economies and Labour Productivity: Evidence from Longitudinal Worker Data for GB's Travel-to-work Areas. SERC Discussion Paper 31. Spatial Economics Research Centre, The London School of Economics and Political Science.
- METRO, 2008. Síntese das Informações Pesquisa Domiciliar. Pesquisa Origem e Destino 2007.
- Miller, Ronald E., Blair, Peter D., 2009. *Input-output Analysis*. Cambridge University Press.
- Peter, M.W., Horridge, M., Meagher, G.A., Naqvi, F., Parmenter, B.R., 1996. The Theoretical Structure of MONASH-MRF. Preliminary Working Paper no. OP-85, IMPACT Project. Monash University, Clayton, VIC.
- Rospabé, S., Selod, H., 2006. Does city structure cause unemployment? The case study of cape town. In: Borat, H., Kanbur, R. (Eds.), *Poverty and Policy in Post-Apartheid South Africa*. HSRC Press, pp. 262–287 2006.
- Shertzer, Allison, Twinam, Tate, Walsh, Randall P., 2016. Zoning and the Economic Geography of Cities. NBER Working Paper No. 22658, September 2016.
- Vieira, R.S., Haddad, E.A., 2015. An accessibility index for the metropolitan region of sao Paulo. In: Kourtit, K., Nijkamp, P., Stough, R.R. (Eds.), *The Rise of the City: Spatial Dynamics in the Urban Century*. Edward Elgar Publishing, Cheltenham, UK 2015.
- Van Ommeren, J., Gutiérrez-I-Puigarnau, E., 2009. Are Workers with a Long Commute Less Productive? an Empirical Analysis of Absenteeism. Tinbergen Institute Discussion Paper, TI 2009-014/3.
- Villaça, F., 2011. São Paulo: Segregação Urbana e Desigualdade. *Estudos Avançados*, São Paulo, v. 25, n. 71.
- World Bank, 2008. Brazil, Evaluating the Macroeconomic and Distributional Impacts of Lowering Transportation Costs. Report No 40020-BR.
- Zenou, Y., 2002. How do firms redline workers? *J. Urban Econ.* 52, 391–408.